



Biogeographic Assessments: The Integration of Ecology and GIS to Support Fishery Science and Management

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National Centers for Coastal Ocean Science-Center for Coastal Monitoring & Assessments

Abstract

The National Centers for Coastal Ocean Science/Center for Coastal Monitoring and Assessment's Biogeography Program develops information and analytical capabilities through research and assessments on the distribution and ecology of living marine resources and their associated habitats for improved ecosystem management. The foundation of the program is based upon a biogeographic assessment process that defines the distribution of habitats, species distributions, and the coupling of species to habitats. The presentation will provide case examples of GIS-based applications to define species habitat utilization patterns and define ecologically relevant management boundaries (e.g., MPAs). The work is underway in marine, coastal, estuarine, and coral reef ecosystems and digital map products are developed from the integration of ecology and GIS technology based on the principles of biogeography. Results from estuarine assessments to define essential fish habitat (EFH), marine analyses to evaluate existing MPA boundaries, and research to define reef fish habitat utilization patterns will be presented to demonstrate the use of GIS technology. Example outputs from GIS desktop applications will be shown and the success and challenges of developing ecological GIS tools will be discussed.

Biogeographic Assessments: The Integration of Ecology and GIS to Support Fishery Science and Management

NOS/NCCOS/CCMA Biogeography Program

Marine Biogeography: *The spatial and temporal patterns of living marine resources, their associated habitats, and the historical and current environmental factors influencing species distributions.*

<http://biogeo.nos.noaa.gov>

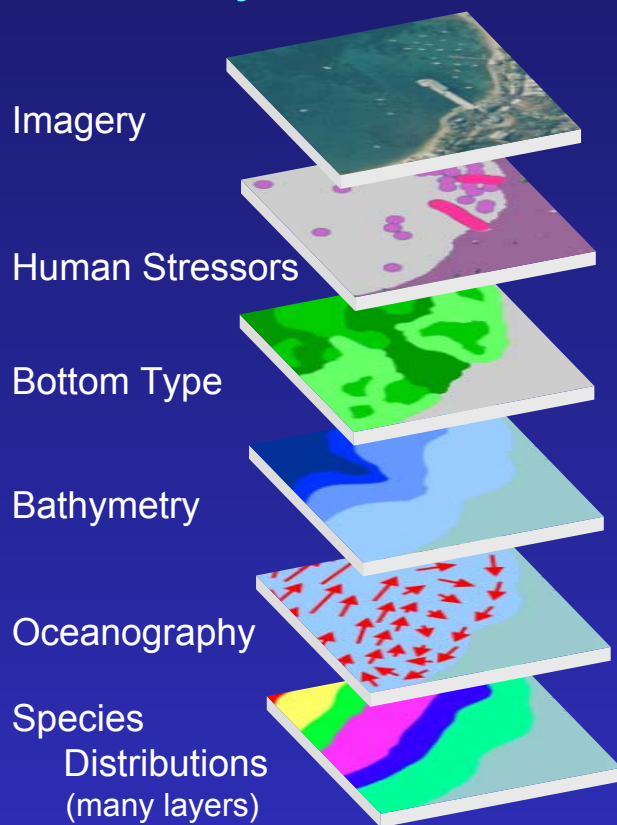
mark.monaco@noaa.gov

Presentation Outline

- **Introduction & Biogeographic Assessment Process**
- **Representative Studies**
 - **Estuarine Ecosystems**
 - **ELMR**
 - **Habitat Suitability Modeling**
 - **Marine Ecosystems**
 - **Coastal/Northern California**
 - **Coral Reef Ecosystem**
 - **Reef Fish Habitat Utilization**
- **Desktop System Development (EcoGIS??)**
 - **Coastal Ocean Resource Assessment (CORA)**
 - **Habitat Suitability Modeling (HSM)**
 - **GIS Development**
 - **User Needs**
 - **Training**

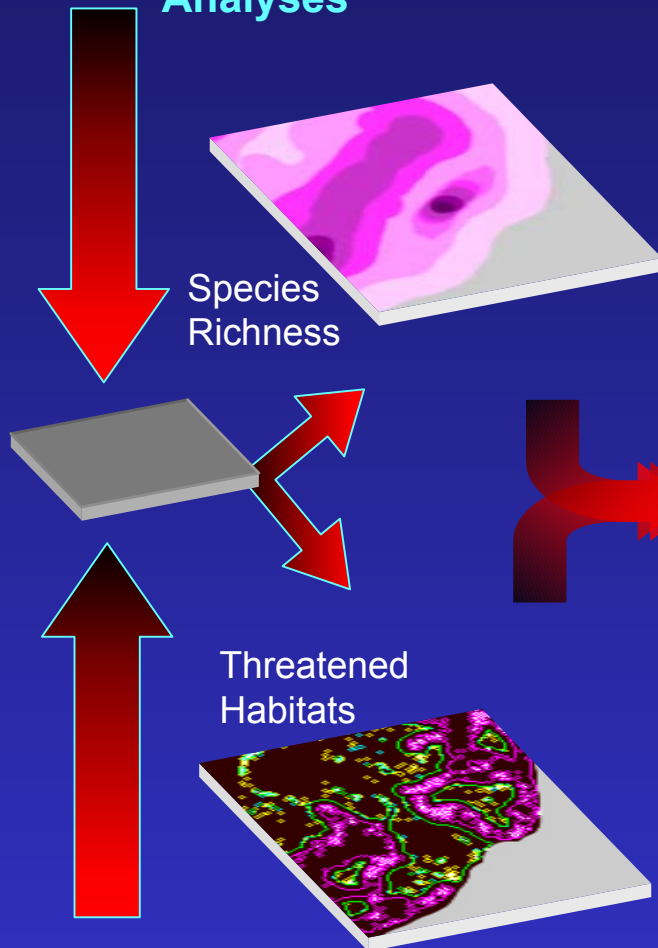
The Biogeographic Assessment Process

Individual Biogeographic Data Layers



(Kendall & Monaco 2003)

Combine Biogeographic Layers for Analysis



Example Integrated Biogeographic Analyses*

Analytical Products to meet Management Objectives

Products to Aid Natural Resource Management

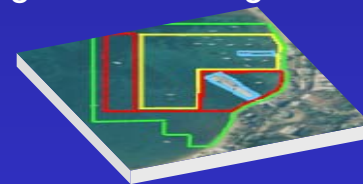
Evaluate current management boundaries relative to biological resources



Explore options for protecting additional management areas

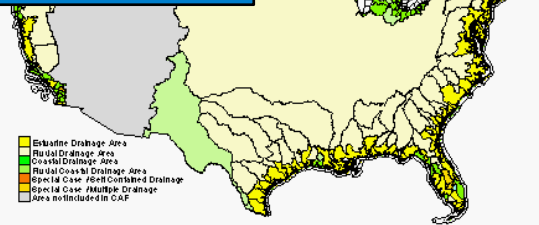


Evaluate Alternative Management Strategies

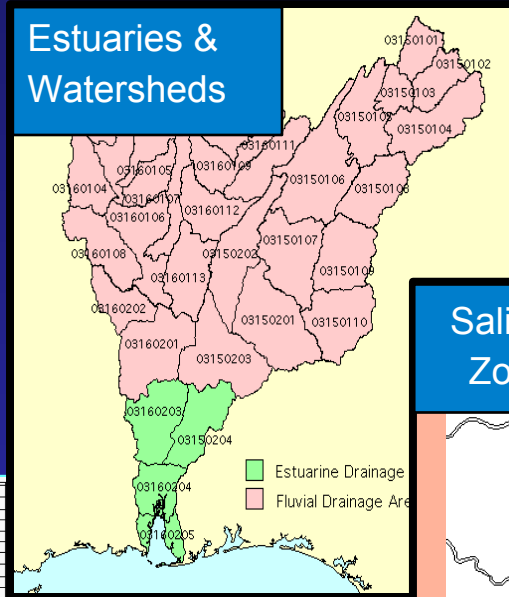


Multiple Spatial Geographies

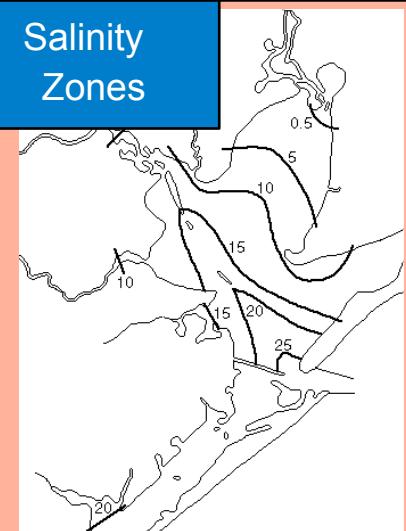
National Framework



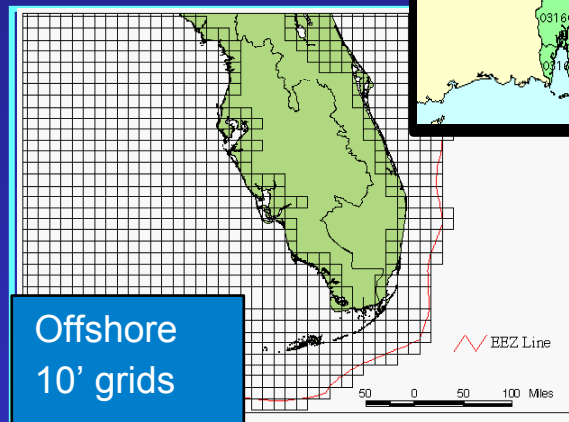
Estuaries & Watersheds



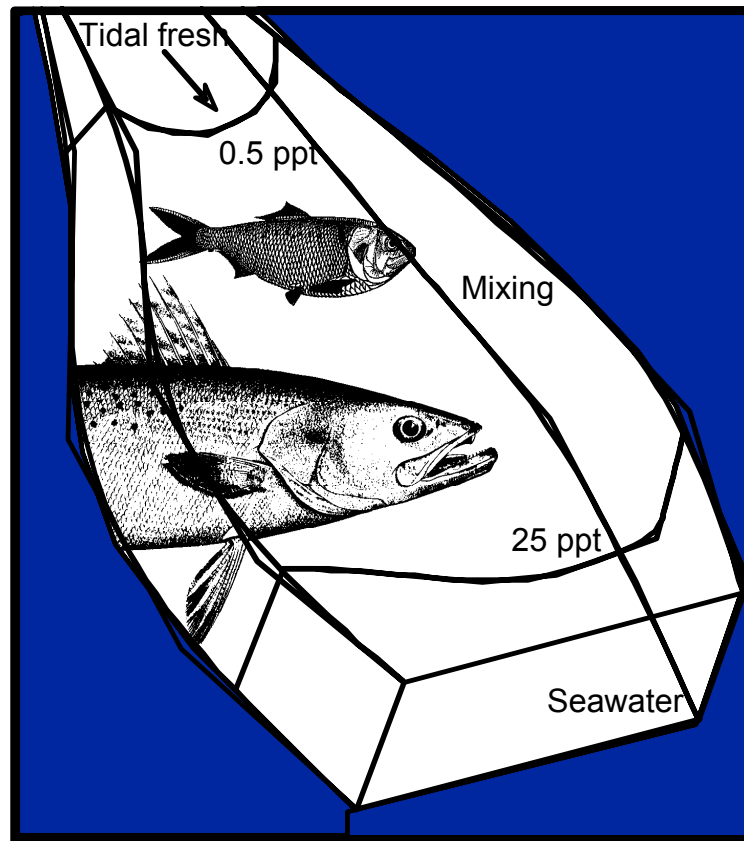
Salinity Zones



Offshore
10' grids



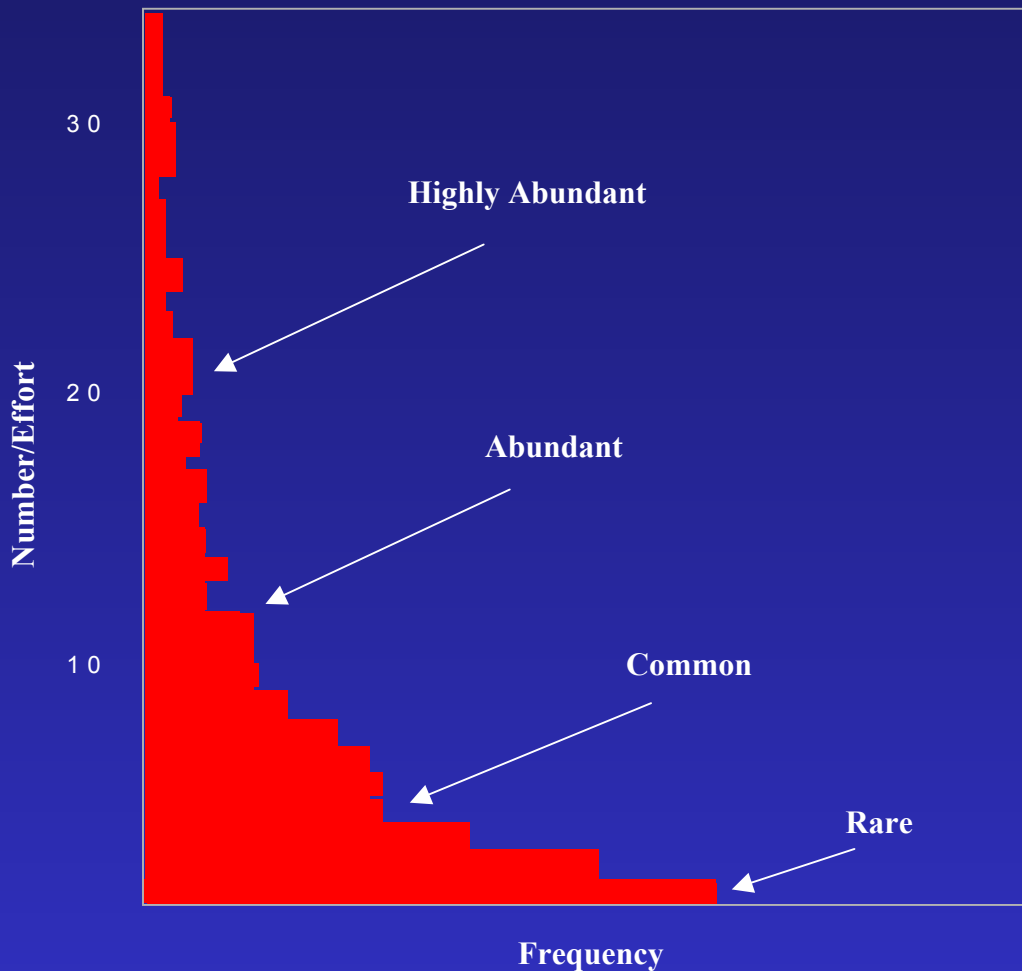
Estuarine Living Marine Resources (ELMR) Program



(Nelson and Monaco, 2000. NOAA Tech. Memo. NOS 144)

Catch Data (FIM)

Bag Seine: Shallow Water Fishes (TPWD data)



Quantiles

100.0%	32.790	Highly Abundant
99.5%	32.102	
97.5%	29.500	
90.0%	20.330	Abundant
75.0%	11.793	
50.0%	5.730	
25.0%	2.500	Common
10.0%	1.210	
2.5%	1.000	
0.5%	1.000	Rare
0.0%	1.000	

Moments

Mean	8.315
Std Dev	7.648
Std Error Mean	0.225
Upper 95% Mean	8.756
Lower 95% Mean	7.873
N	1154.000
Sum Weights	1154.000

ELMR Data Sheet

COMMON NAME: Alewife
SCIENTIFIC NAME: *Alosa pseudoharengus*

ESTUARY: Cape Fear River
STATE: North Carolina

Salinity Zone	Life Stage	Relative Abundance by Month												R
		J	F	M	A	M	J	J	A	S	O	N	D	
Zone 1 0.0 - 0.5‰	Adults	Rare												1
	Spawning	No Data												1
	Juveniles	Rare												1
	Larvae	No Data												1
	Eggs	Rare												1
Zone 2 0.5 - 5‰	Adults	Common												2
	Spawning	No Data												1
	Juveniles	Common												2
	Larvae	Abundant												2
	Eggs	No Data												2
Zone 3 5 - 15‰	Adults	Common												3
	Spawning	No Data												1
	Juveniles	Abundant												3
	Larvae	Abundant												1
	Eggs	Rare												1
Zone 4 15 - 25‰	Adults	Common												2
	Spawning	No Data												2
	Juveniles	Abundant												1
	Larvae	Abundant												3
	Eggs	Rare												1
Zone 5 >25.0‰	Adults	Abundant												3
	Spawning	Common												1
	Juveniles	Abundant												1
	Larvae	No Data												1
	Eggs	Rare												2

LEGEND

Relative Abundance

	= Not Present
	= No Data
	= Rare
	= Common
	= Abundant
	= Highly Abundant

Data Reliability (R)

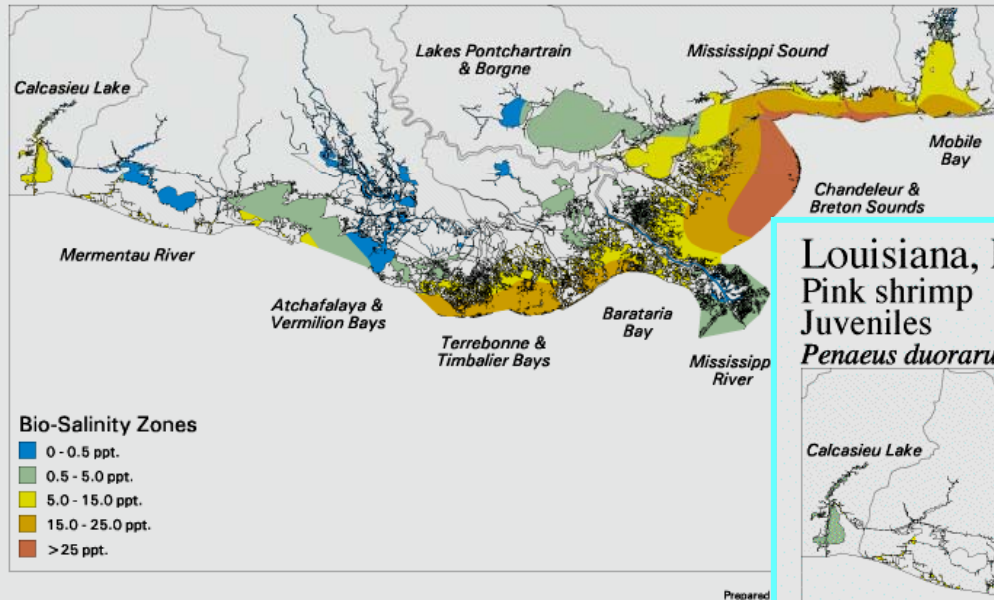
1 = Highly Certain
2 = Moderately Certain
3 = Reasonable Inference

ELMR Database



Coupling Habitat & Species Distribution

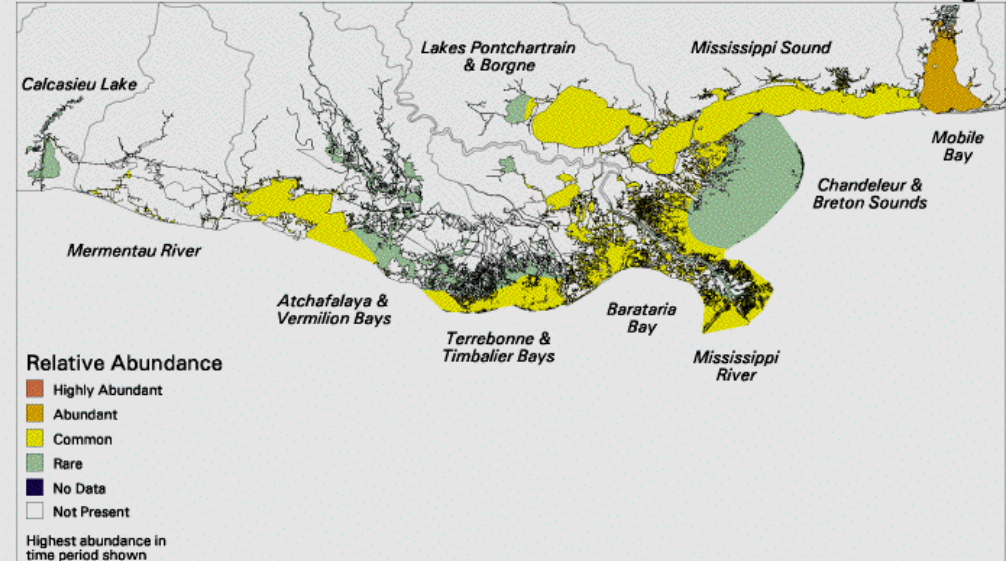
Louisiana, Mississippi, and Alabama
Summer (Jun. - Aug.)



Digital Map
Products

Louisiana, Mississippi, and Alabama
Pink shrimp
Juveniles
Penaeus duorarum

Summer (Jun. - Aug.)



Prepared for the Gulf of Mexico Fishery Management Council
NOAA/SEA Division
February, 1998

(SEA, SEFSC, GMFMC, 1998))

(Rubec et al. 1998 Fisheries (23): 21-25)

GIS-Based Habitat Suitability Models

A Habitat-Use Model to Determine Essential Fish Habitat for Juvenile Brown Shrimp in Galveston Bay, Texas

Randal D. Clark

John D. Christensen

Mark E. Monaco

NOAA/National Ocean Service

NCCOS/CCMA

Biogeography Team

Silver Spring, MD

Thomas J. Minello

Phillip A. Caldwell

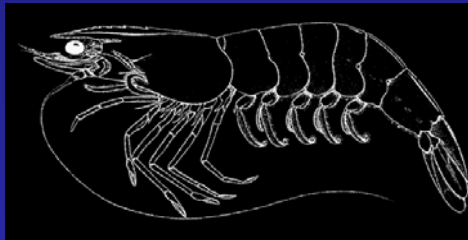
Geoffrey A. Mathews

NOAA/National Marine Fisheries Service

Southeast Fisheries Science Center

Galveston, TX

(Clark et al. 2004. Fish. Bull. (102):264-277)



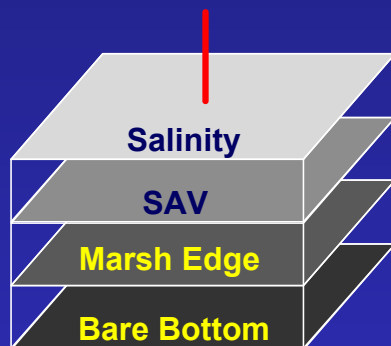
GIS-Based Habitat Suitability Modeling

Statistical Model

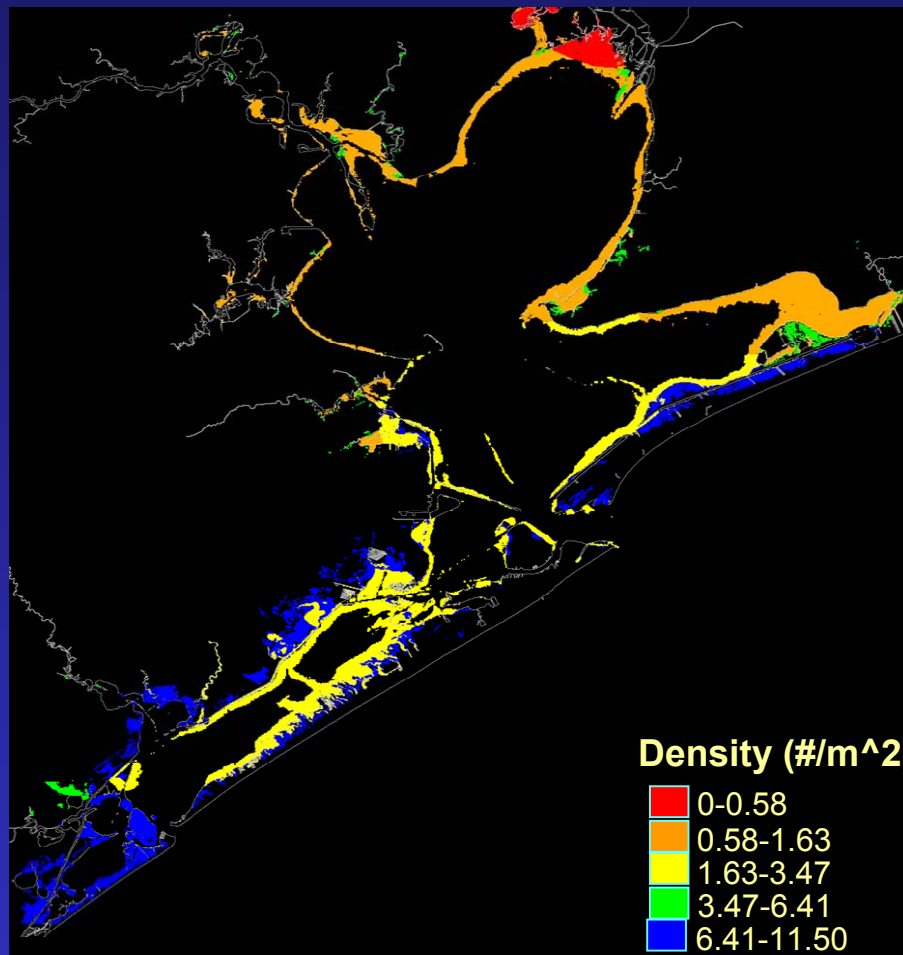
$$Y = a + b_{y1} \cdot X_1 + b_{y2} \cdot X_2 + \dots + b_{yk} \cdot X_k$$

Where $X_{(1-k)}$ = Habitat variables

SEASON
Salinity
SAV
Marsh Edge
Non-Vegetated Bottom

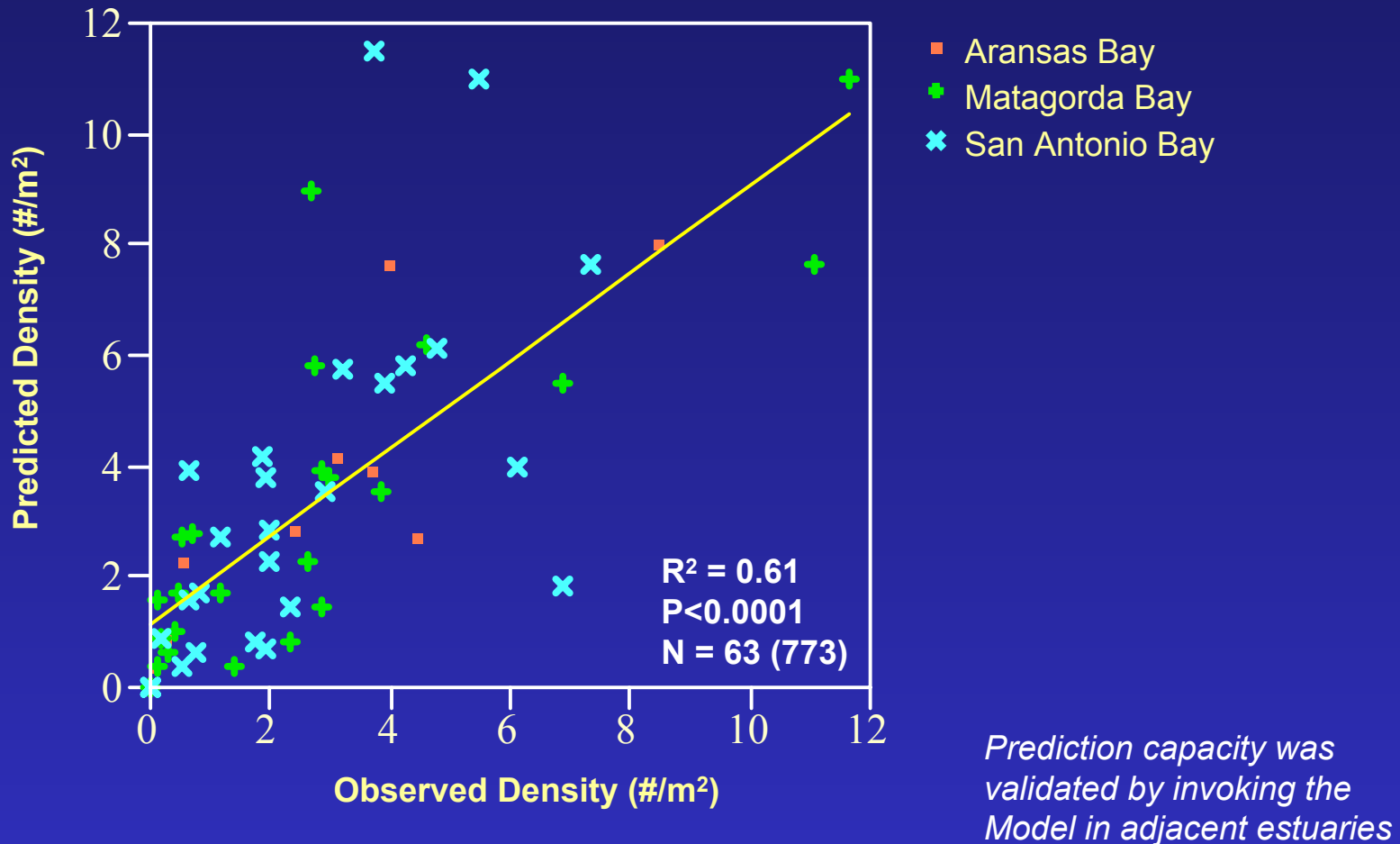


GIS Layers



(Battista & Monaco 2004, GIS Apps in Coastal Mar Fisheries, AFS: 189-208)

GIS-Based Habitat Suitability Modeling



(Clark et al. 2004. Fish. Bull. (102):264-277)

Biogeographic Assessments of NOAA National Marine Sanctuaries: The Integration of Ecology and GIS Technology.

(Monaco et al. In Press: Place Matters: Geospatial Tools for Marine Conservation, Science and Management in Pacific Northwest, (OSU Press))



Representative Study:
*A Biogeographic Assessment of the Marine Region
Encompassing the Cordell Bank, Gulf of the Farallones,
and Monterey Bay National Marine Sanctuaries*

(NOAA/NCOSS 2003 145p Atlas & CD-ROM)

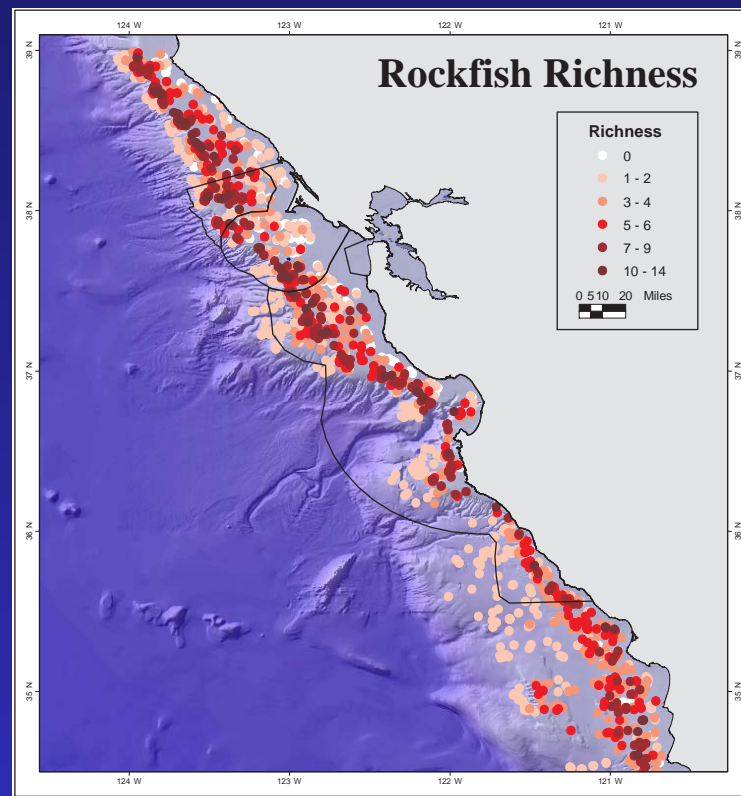
Community Metrics

Main Objective:

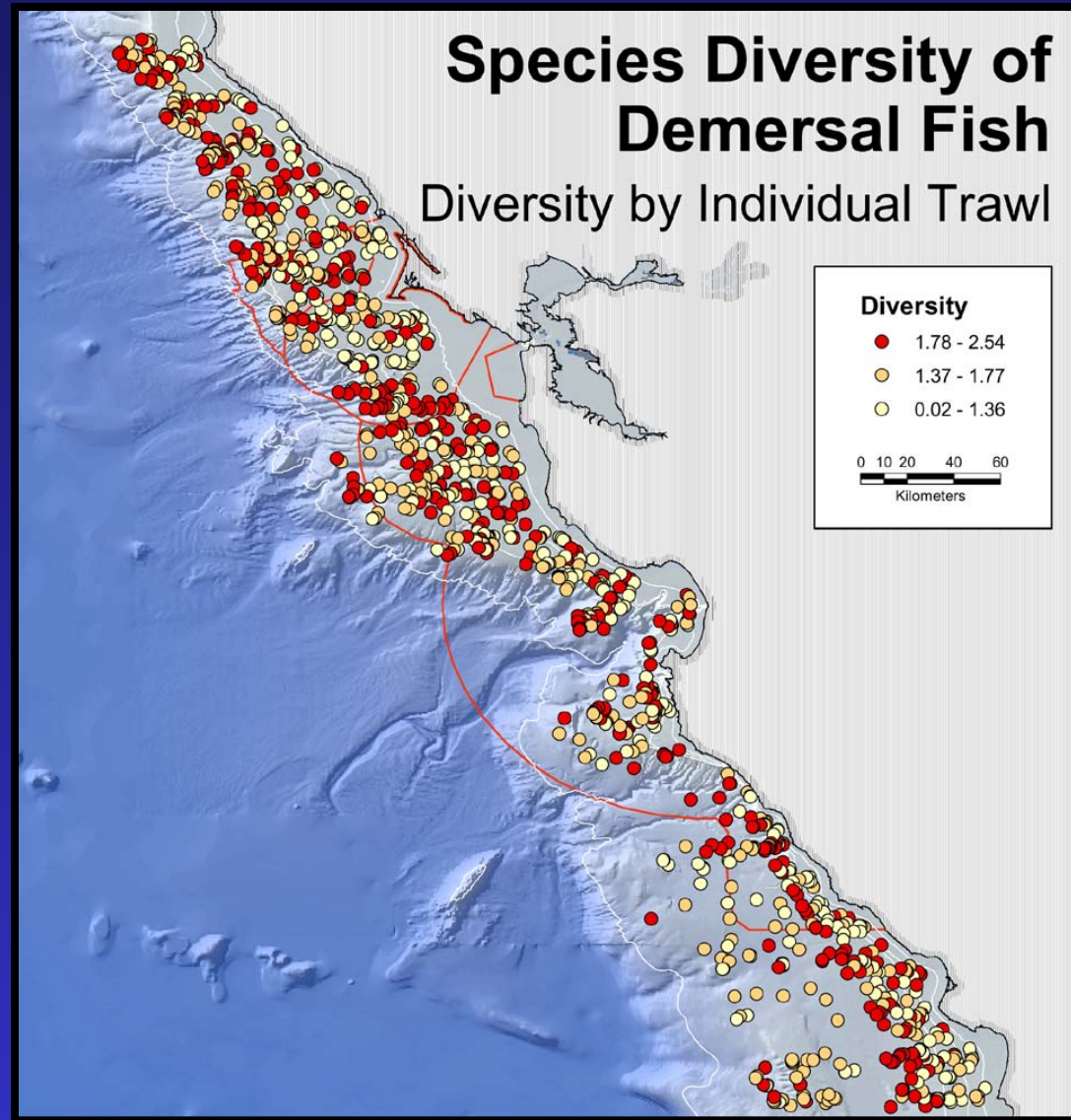
- Determine where areas of high benthic fish species diversity and richness exist within the study area.

Methods:

- Data sets: NMFS benthic shelf and slope trawls.
- Richness and Diversity (Shannon-Wiener) were calculated individually for each trawl.
- Mean richness and diversity are mapped to show spatial results in 9x9 minute grid cells.
- Caveats exist due to the trawl methods used and the temporal and spatial constraints of the data.



Community Metrics

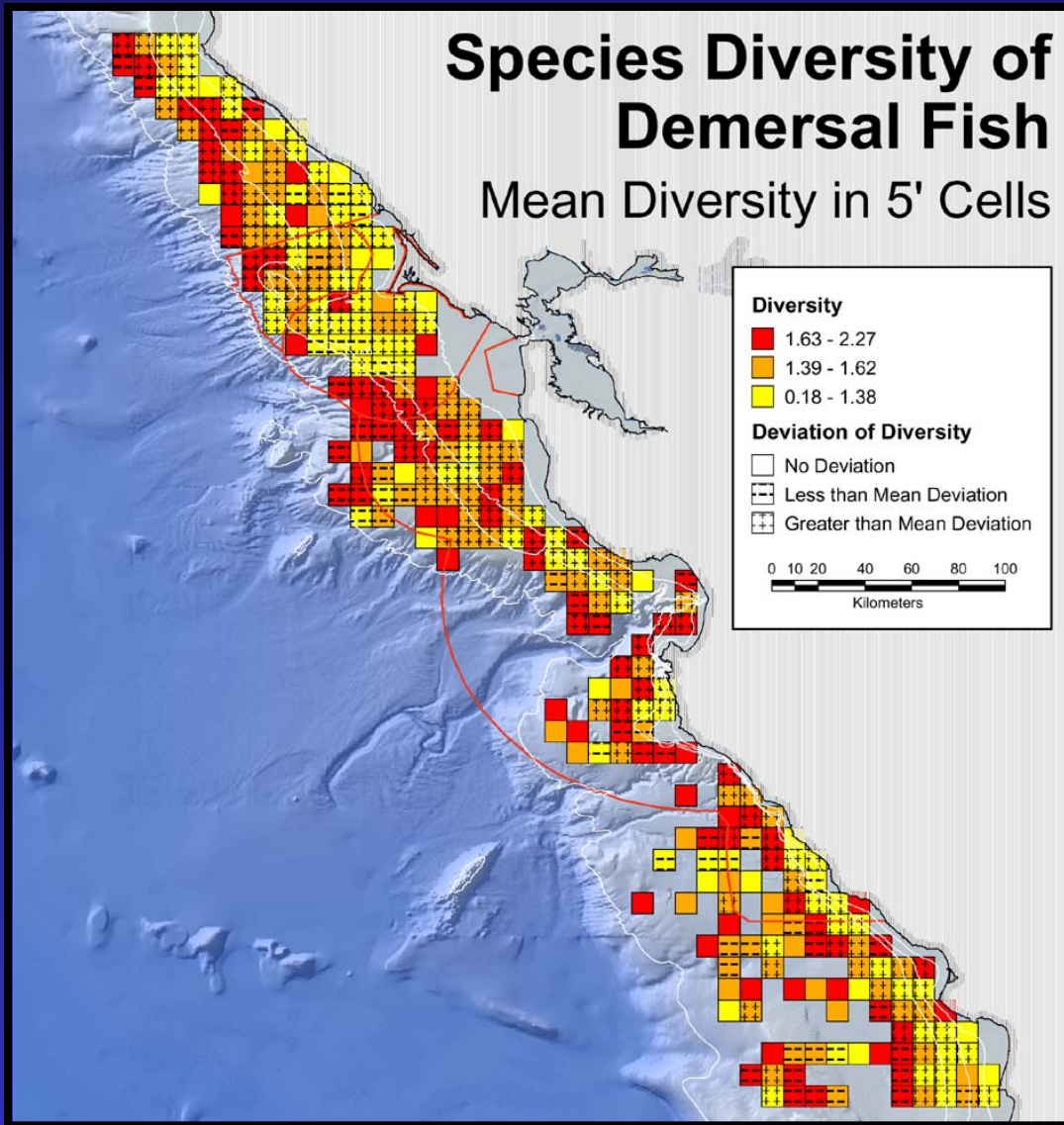


EXAMPLE I: Fishes

Simple Distributions

- Most precise geo-location,most difficult to interpret
- Can extract underlying spatial covariates to construct models (e.g., bathymetry, substrate, etc.)
- Species-level estimates (e.g., abundance, biomass, etc.)
- Community-level estimates (e.g., richness, diversity, statistical “classifications” and “ordinations”, etc.)

Community Metrics

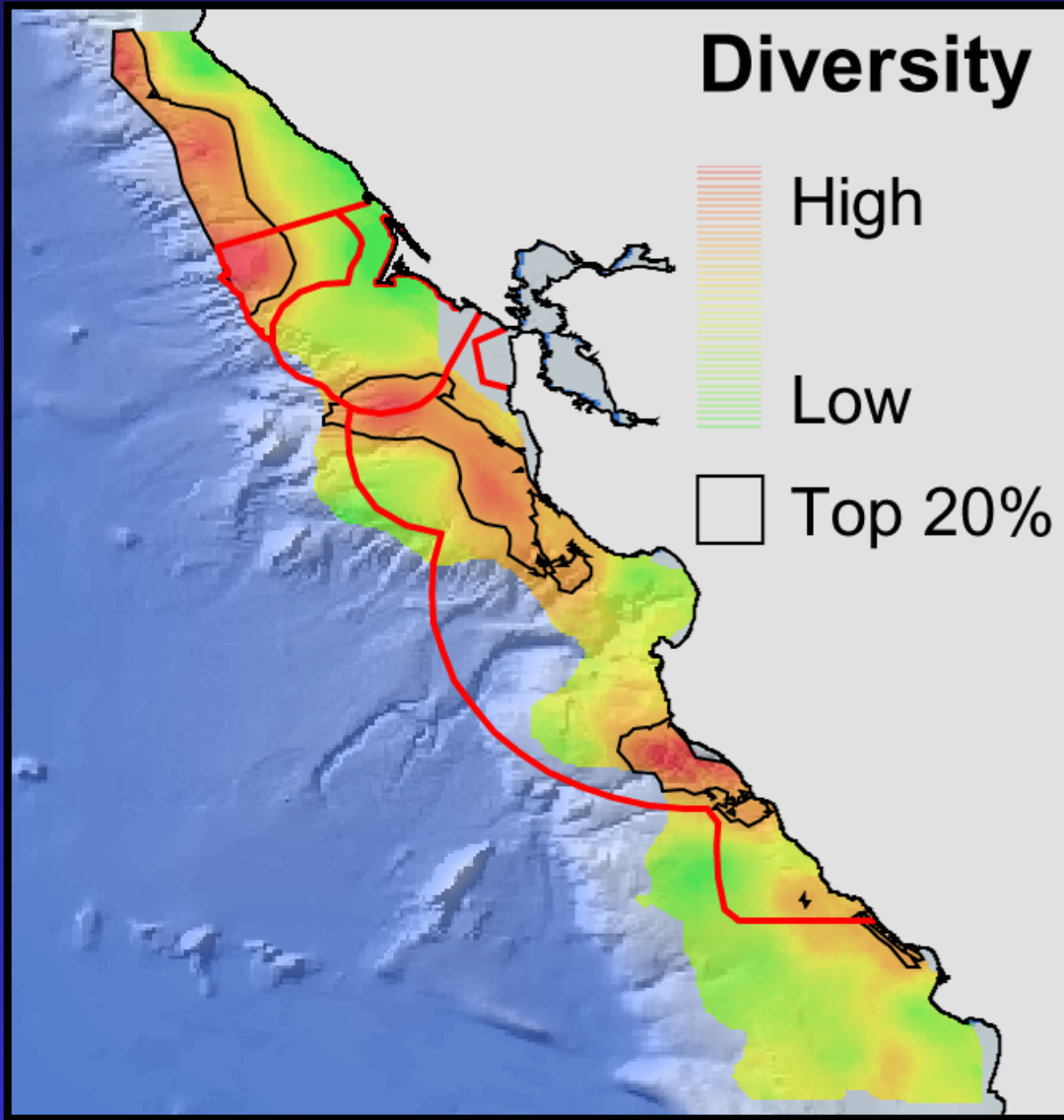


EXAMPLE II: Fishes

Spatial Summaries

- 5 minute grid spatial framework
- “Descriptive” Statistics
 - Minimum
 - Maximum
 - Mean
 - Variance
- Essentially a smoothing technique
- Effort adjusted

Community Metrics



EXAMPLE III: Fishes

Geo-Spatial Modeling

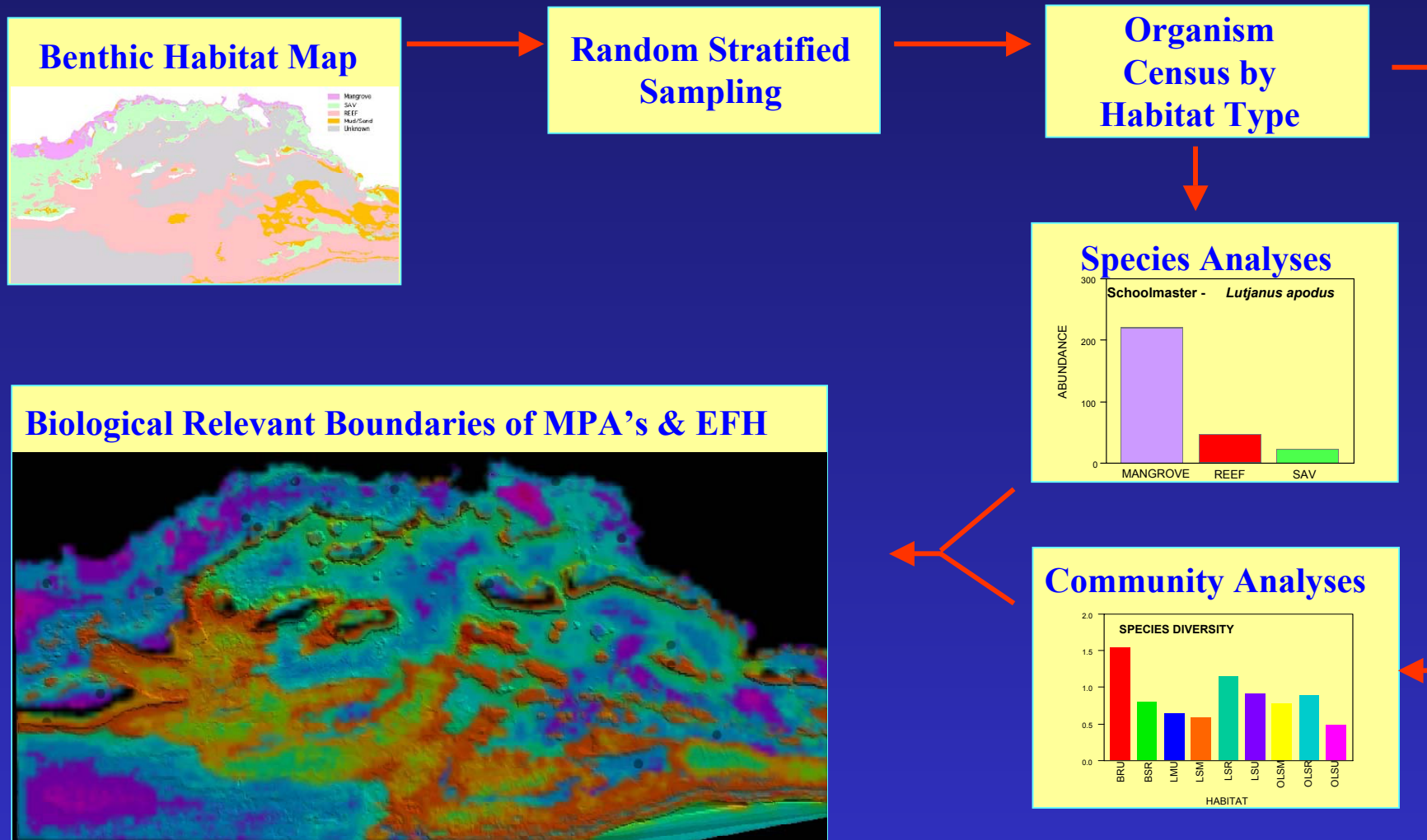
- Test for spatial autocorrelation (Moran's, Geary's)
- Describe & model autocorrelation (Variogram)
- Use empirically derived parameters to "guide" surface interpolation (Kriging)
- Effort Modeled (Spatially articulated residuals)

Reef Fish Habitat Utilization Patterns in US Caribbean

(Monaco et al. 2003. Proc. 13th Coastal Zone Conference)



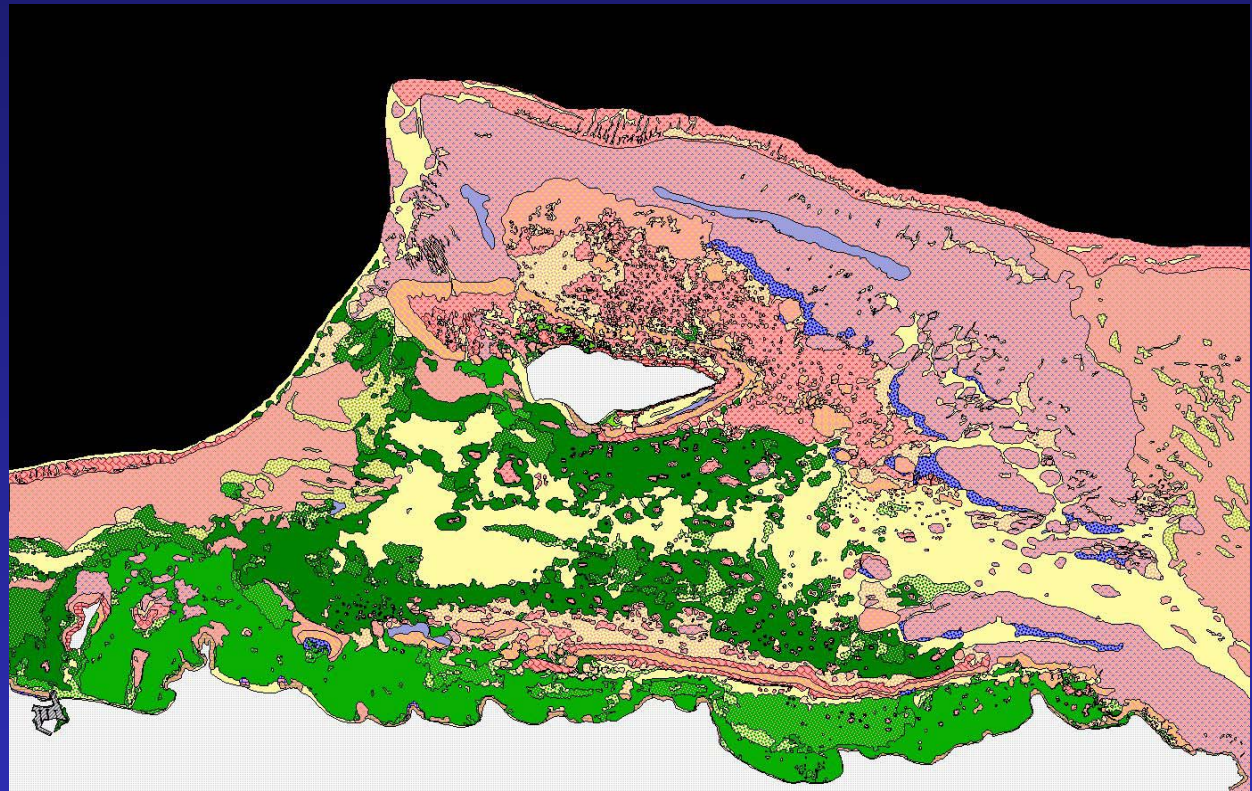
Coupling of Maps & Species Habitat Utilization Patterns



Example Benthic Habitat Map St. Croix, USVI

Habitat

-  Sand
-  Mud
-  Seagrass/Continuous
-  Seagrass/70-90%
-  Seagrass/50-70%
-  Seagrass/30-50%
-  Seagrass/10-30%
-  Macroalgae/Continuous
-  Macroalgae/Patchy/50-90%
-  Macroalgae/Patchy/10-50%
-  Reef/Linear Reef
-  Reef/Spur and Groove Reef
-  Reef/Patch Reef (Individual)
-  Reef/Patch Reef (Aggregated)
-  Reef/Scattered Coral-Rock
-  Reef/Colonized Pavement
-  Reef/Colonized Bedrock
-  Reef/Col. Pav. with Chan.
-  Hardbottom/Reef Rubble
-  Hardbottom/Uncol. Pav.
-  Hardbottom/Uncol. Bedrock
-  Hardbot./Uncol. Pav. with Chan.
-  Land
-  Mangrove
-  Artificial
-  Unknown
-  No Attributes

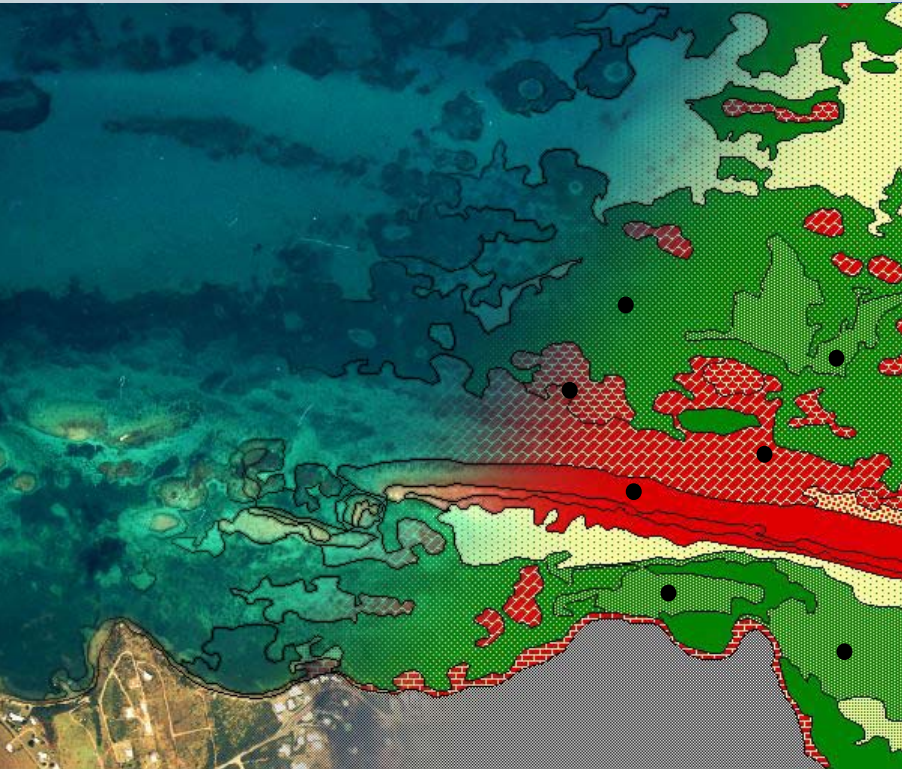


Habitat map of Eastern St. Croix and BIRNM

(Kendall et al. 2004, Aquatic Cons (14): 113-132)

(Kendall et al. 2002 NOAA Tech Memo CCMA 152)

Integration of Mapping, Monitoring & Assessments



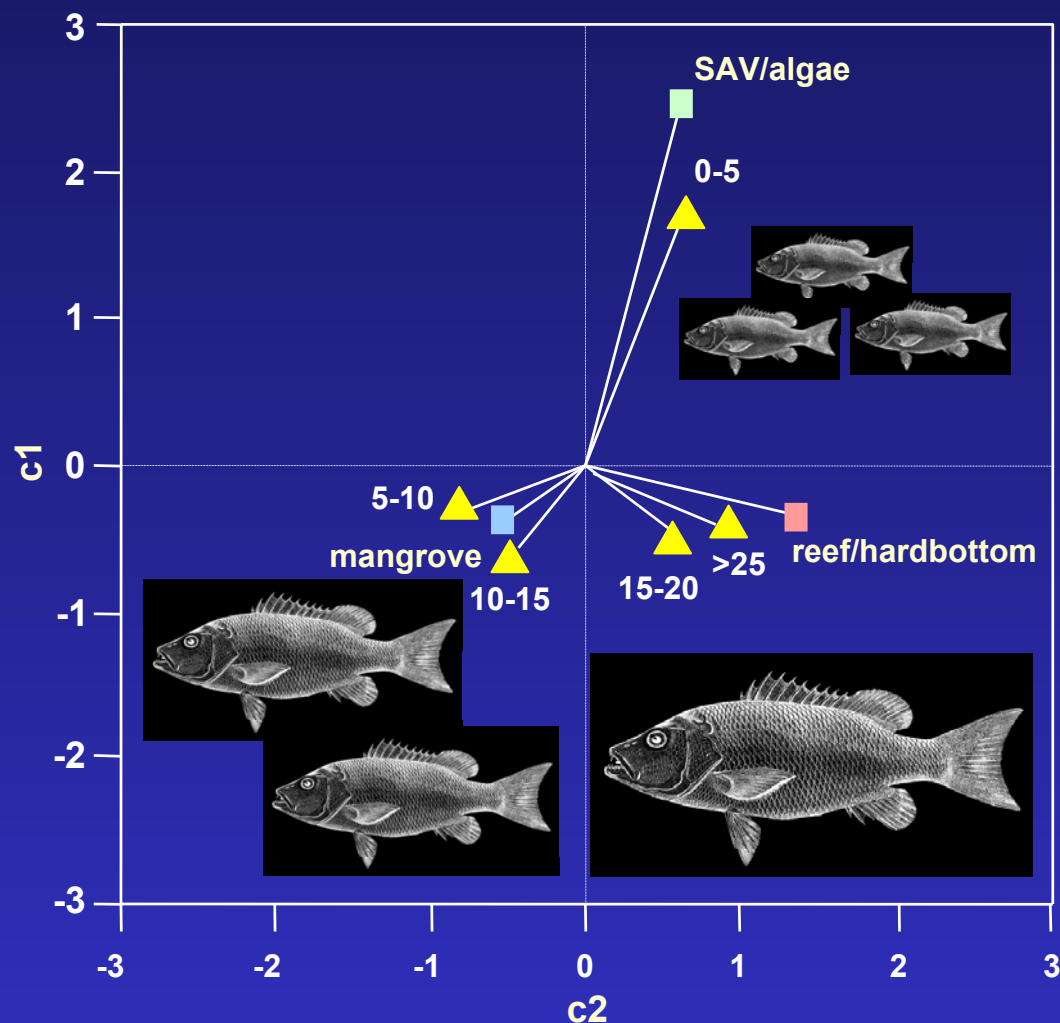
Habitat maps



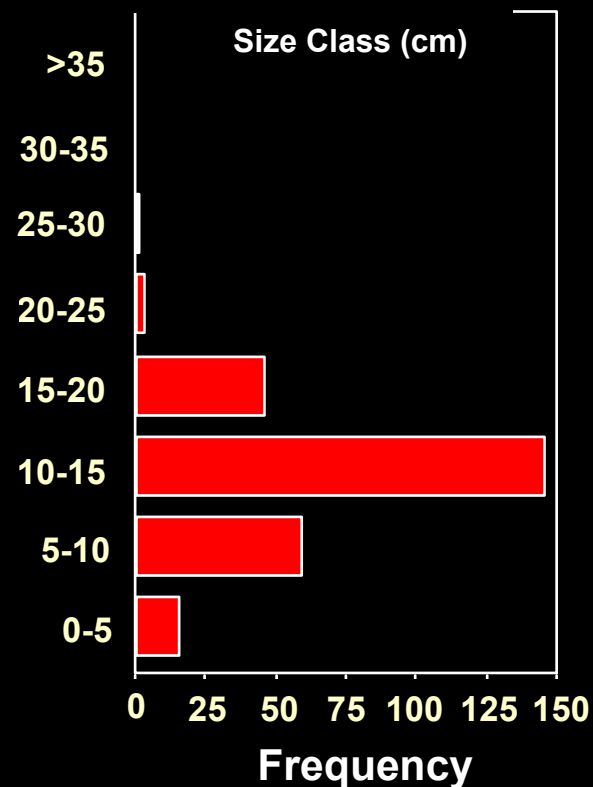
Divers collecting benthic habitat, fish size, and abundance data.

(Monaco et al. 2001, Earth System Monitor (12), No 1)

Gray Snapper Habitat Utilization



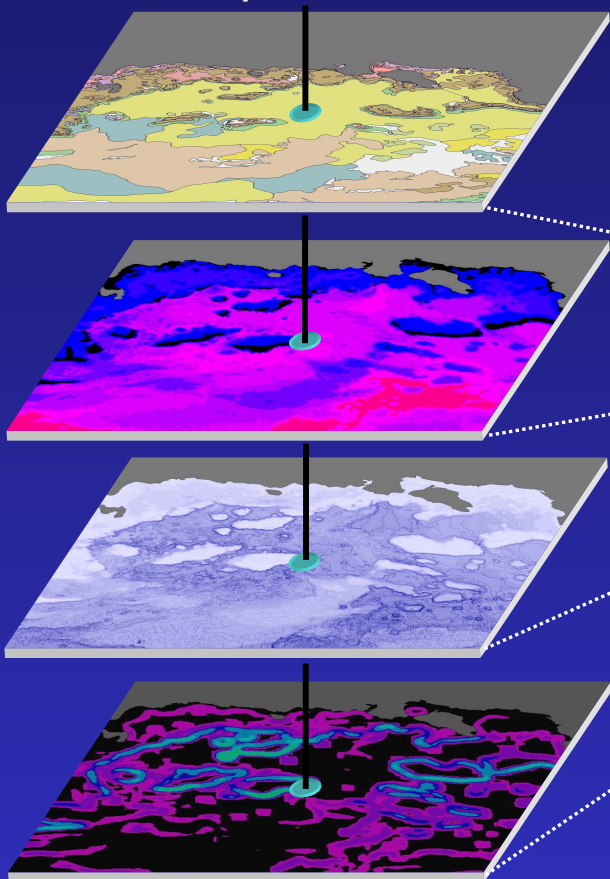
In this example, smaller snappers (0-5cm size class) were observed to select for submerged vegetation, while intermediate sized fishes (5-15cm) selected for mangrove habitats, and the largest size classes (15+ cm) selected for reef structure.



(Christensen et al. 2003: Gulf and Caribbean Res. Vol. 14(2):9-27.)

Coupling Habitat & Biological Data

Drill Through Spatial Layers Example: STATION X



CREATING THE ANALYSIS MATRIX

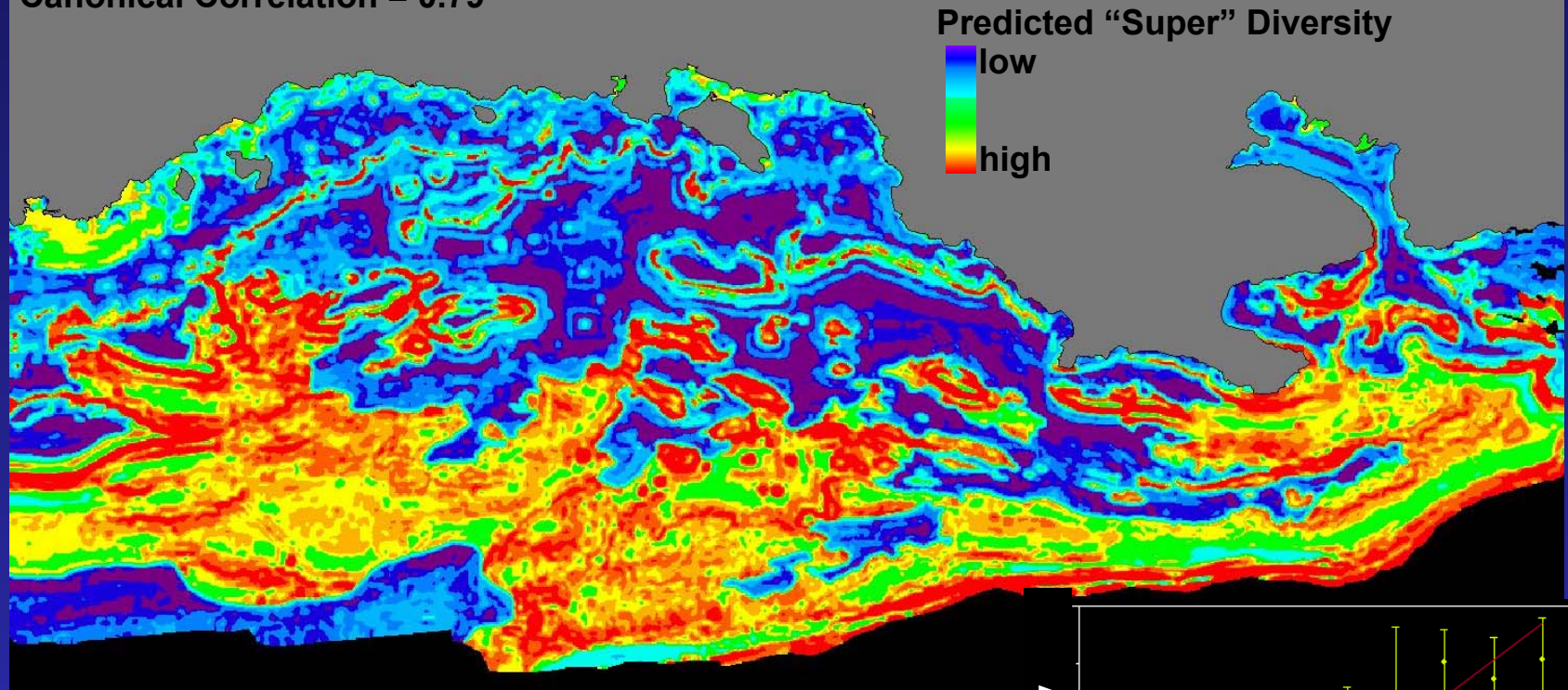
STATION	HABITAT	HAB VARIANCE	DEPTH	DEPTH VARIANCE	RICHNESS	DIVERSITY	ABUNDANCE
	→	→	→	→	→	→	→



This is Done for the Following Variance Resolutions:
60,100, 200, 300, 500, 1000 m
Base Resolution for all Grids is 20 meters

Results: Southwestern Puerto Rico

Canonical Correlation = 0.79

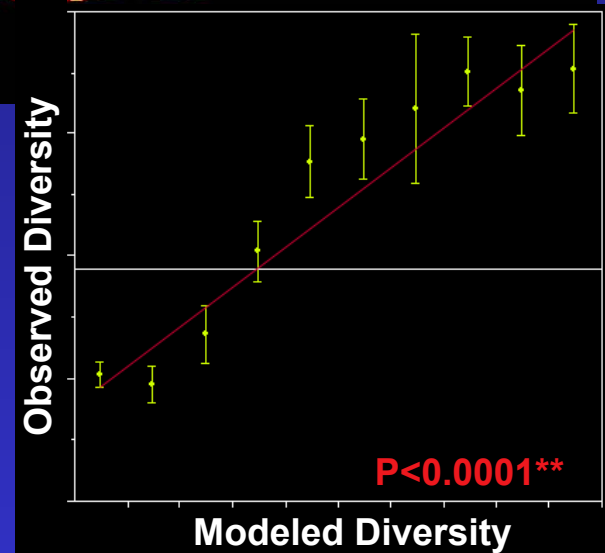


This map represents the canonical solution between landscape-level physiographic and fish community structure data.

MAP ACCURACY

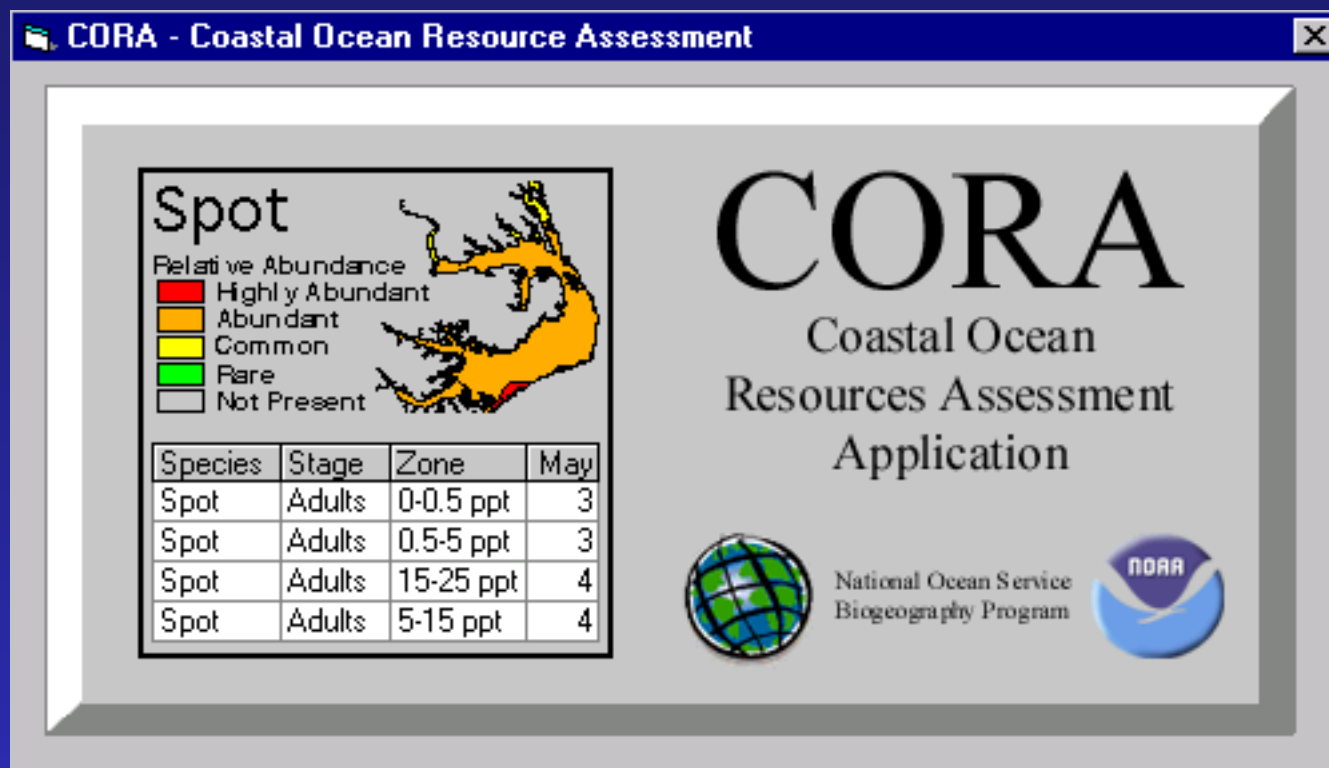
OVERALL

0.77



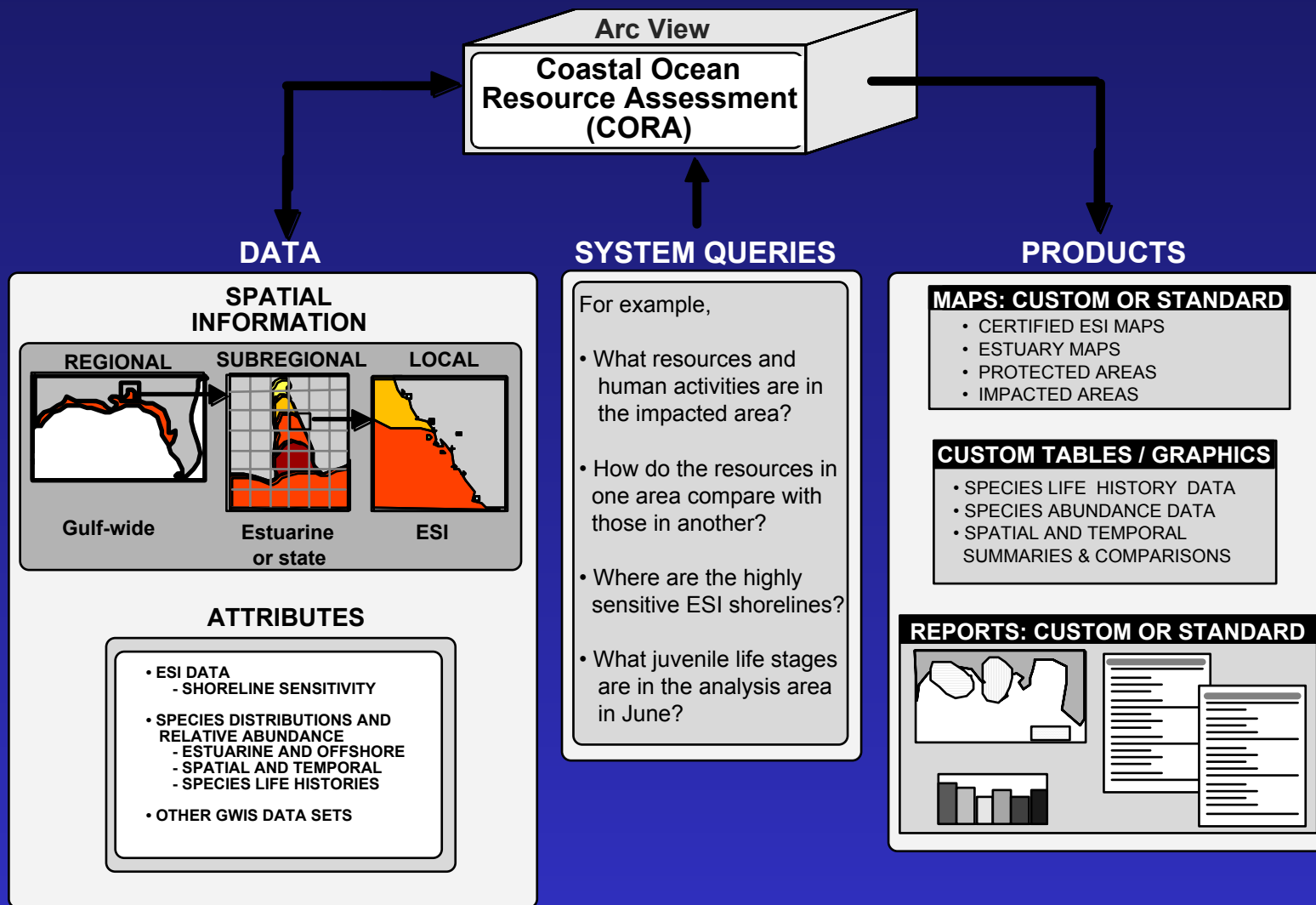
Warm colors represent areas of high "super" diversity derived from species richness, diversity, and abundance data.

Desktop Information Systems



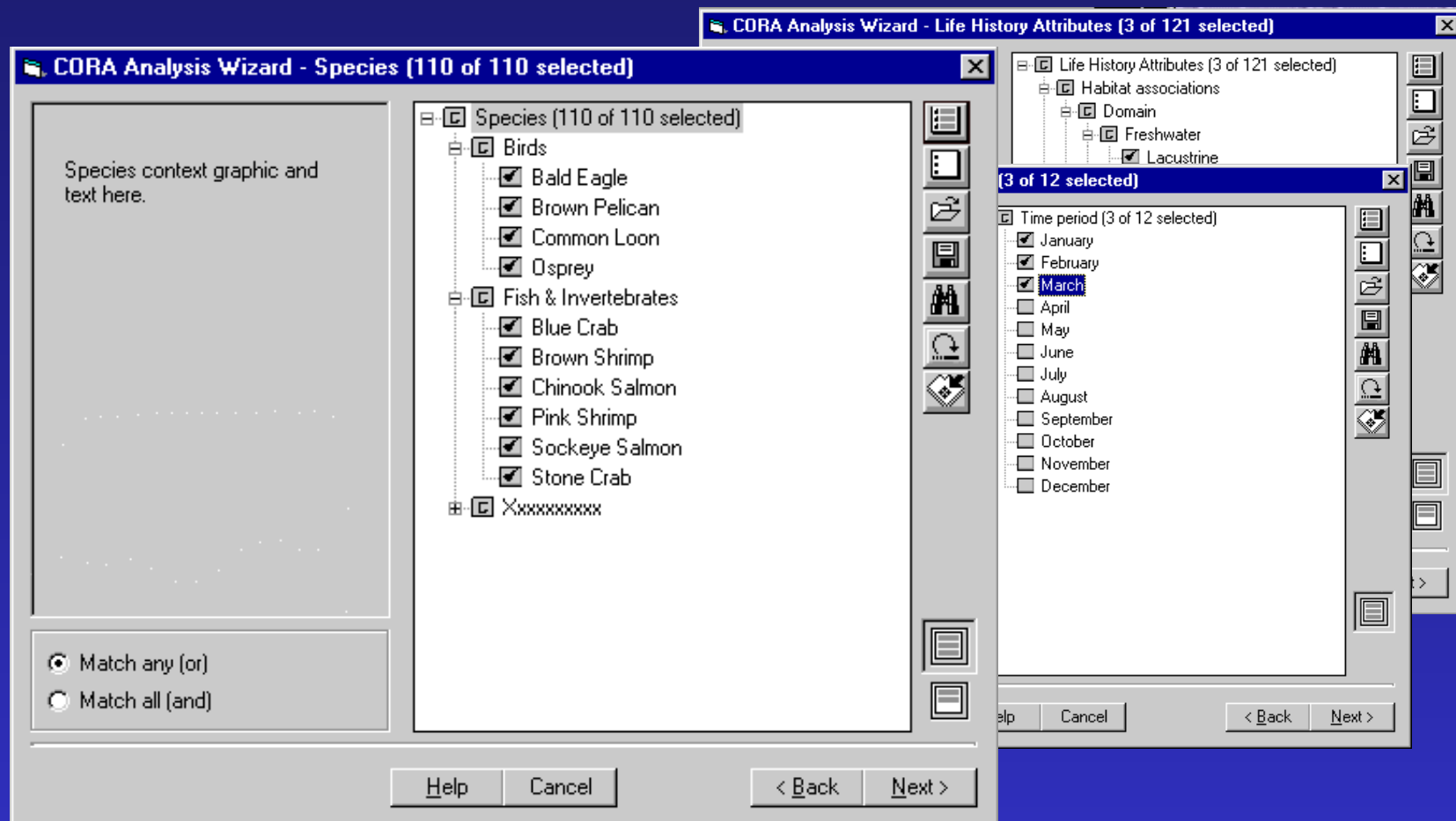
(Gill et al. 2001. Proc. of 1st Int Symp on GIS in Fishery Sci)

Desktop Information Systems



Desktop Information Systems

CORA Wizard Query Setup



Desktop Information Systems

CORA - Results: Reports, Themes and Maps

Reports
 \NOAA\LW 8500 PS-
 Portrait
 Print Export...

☐ Summary
☒ Base area
☐ Target area
☐ Comparison

☐ Affected resource reports
☐ Abundance reports
☒ ELMR estuarine reports
☐ Surveyed data reports

☒ Full ELMR report
☐ By species & life stage
☐ By species & zone
☐ By species

Estuary	Species	Stage	Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
▶ Albemarle Sound	Blueback herring	Juveniles	0-0.5 ppt	2	2	2	2	3	3	3	3	3	3	3	2
Albemarle Sound	Blueback herring	Juveniles	0.5-5 ppt	2	2	2	2	3	3	3	3	3	3	3	2
Albemarle Sound	Blueback herring	Juveniles	15-25 ppt	2	2	2	2	3	3	3	3	3	3	3	2
Albemarle Sound	Blueback herring	Juveniles	5-15 ppt	2	2	2	2	3	3	3	3	3	3	3	2

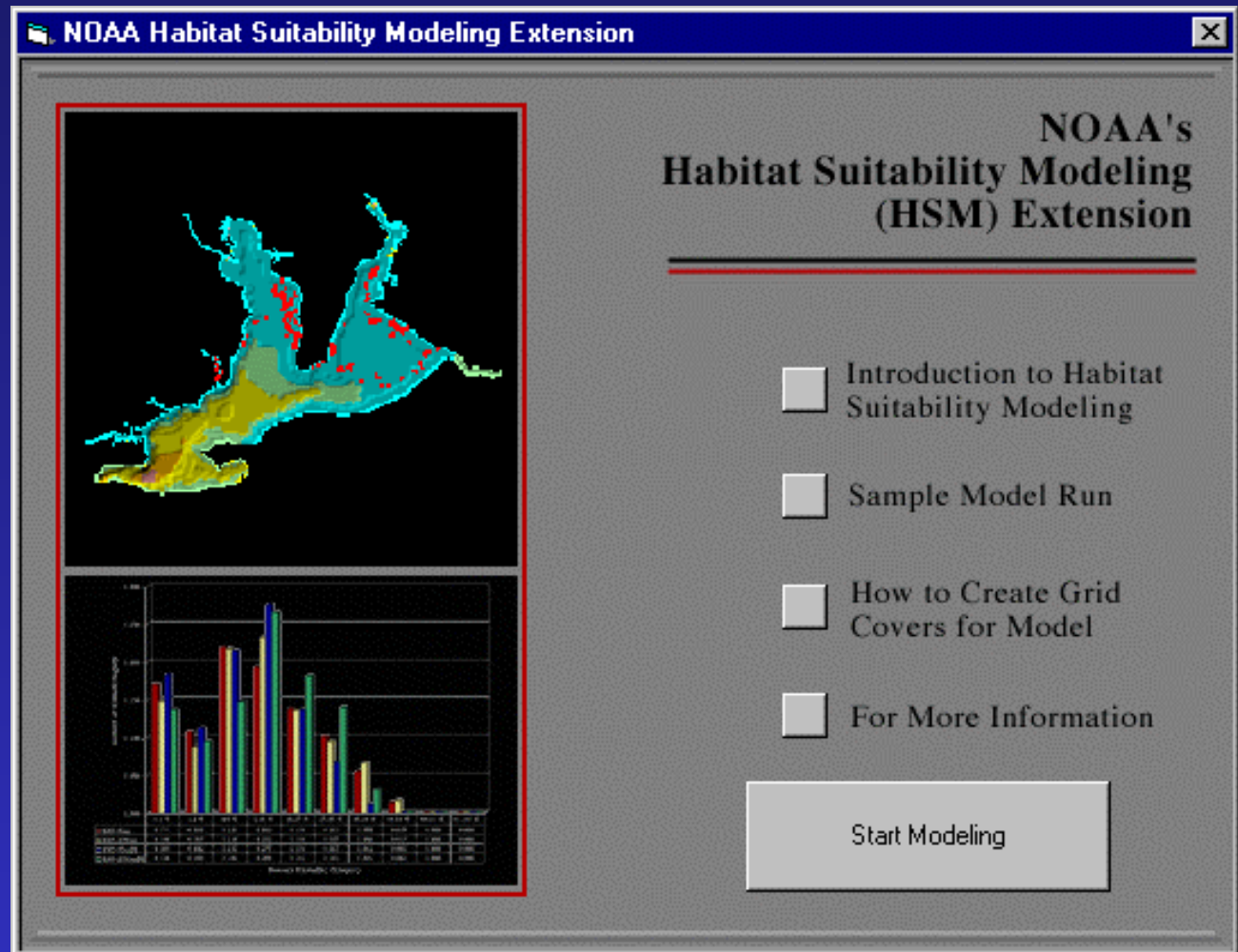
CORA Products: Tables & Maps

blueback juvs in albemarle
☒ Albemarle Sound
☒ ELMR Fish & Invert/Salinity
☐ Blueback herring - Juveniles - W inter
 Rare
☒ Blueback herring - Juveniles - Spring
 Common
☐ Blueback herring - Juveniles - Summer
 Common
☐ Blueback herring - Juveniles - Fall
 Common

About CORA

Desktop Information Systems

Habitat Suitability Modeling: Desktop Information System



(Battista & Monaco 2004, GIS App in Coastal Mar Fish. AFS: 189-208)

Desktop Information Systems

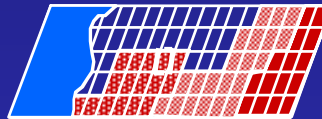
Habitat Suitability Modeling

$$\begin{array}{l} \text{HS Model} \\ \text{(Species Habitat Affinities)} \end{array} + \begin{array}{l} \text{Habitat Map Layers} \\ \text{(Distribution of Habitats)} \end{array} = \begin{array}{l} \text{HS Map} \\ \text{(Distribution of} \\ \text{Suitable Habitats)} \end{array}$$

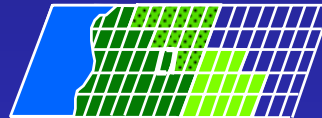
V_1 = TEMPERATURE



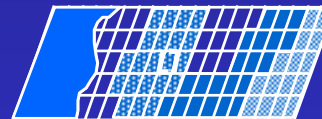
V_2 = SALINITY



V_3 = DEPTH

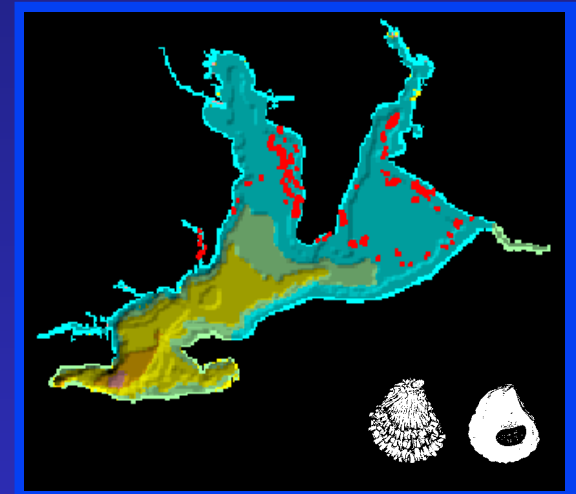


V_4 = SUBSTRATE



$$Y = \left[\prod_{i=1}^n (V_i) \right]^{(1/n)}$$

Example HS Modeling Equation



(Rubec et al. 1998 Fisheries (23): 21-25)

(Rubec et al. 1999. EFH-AFS Symposium (22):108-133)

Habitat Suitability Modeling

HSM Wizard - HSM Algorithm Setup

Geometric Mean Model Equation:

$$HSI = \left[\prod_{i=1}^n (V_i) \right]^{(1/n)}$$

Weighted Geometric Mean Model Equation:

$$HSI = \left[\prod_{i=1}^n (w_i * V_i) \right]^{(1/n)}$$

Standard Multiple Regression Model Equation:

$$Y = a + b_{y1} * x_1 + b_{y2} * x_2 + \dots + b_{yk} * x_k$$

Y = 0.38 + 0.985*PBDEPTHG + 0.25*PBINCSG

a (y intercept) = 0.38

Grid Coefficients:

Grid Name	Grid Coefficient
PBDEPTHG	0.985
PBEVG	0.25
PBINCSG	0.25
PBINCTG	0.25

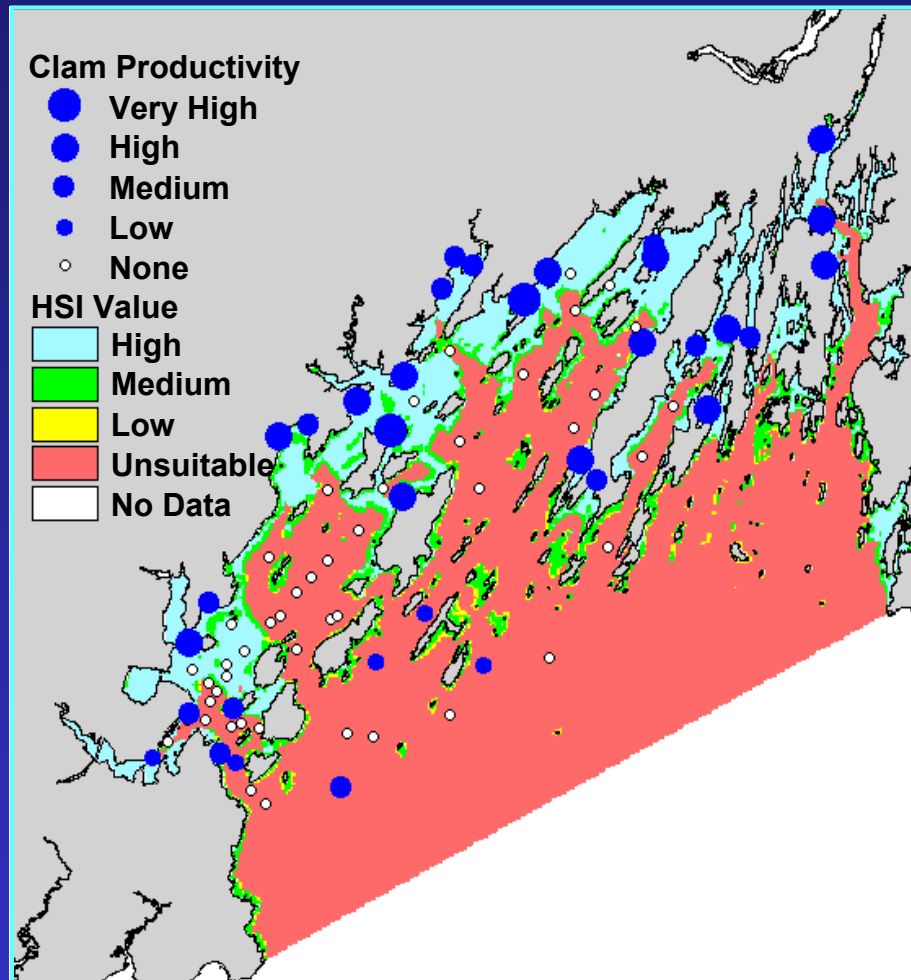
Layers:

Layer Name	Layer Coefficient
(Reclass of PBDEP)	0.25
(PBINCTG)	0.25
(PBINCSG)	0.25
(PBEVG)	0.25
(PBEVG . Count)	0.25
(PBDEPTHG)	0.25

AsGrid

Evaluate

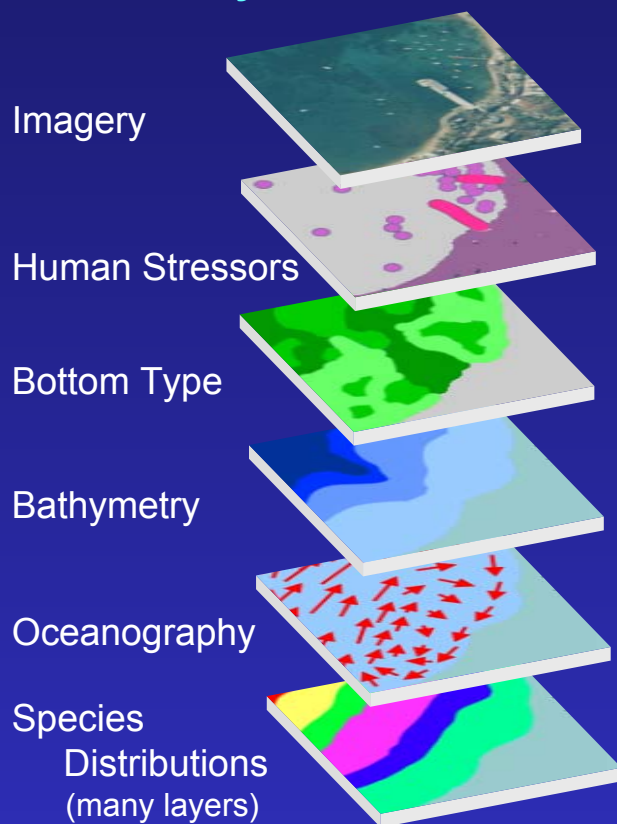
Example Habitat Suitability Model Output



(Brown et al. 2000. N Am J Fish. Mgt. (20):405-435)

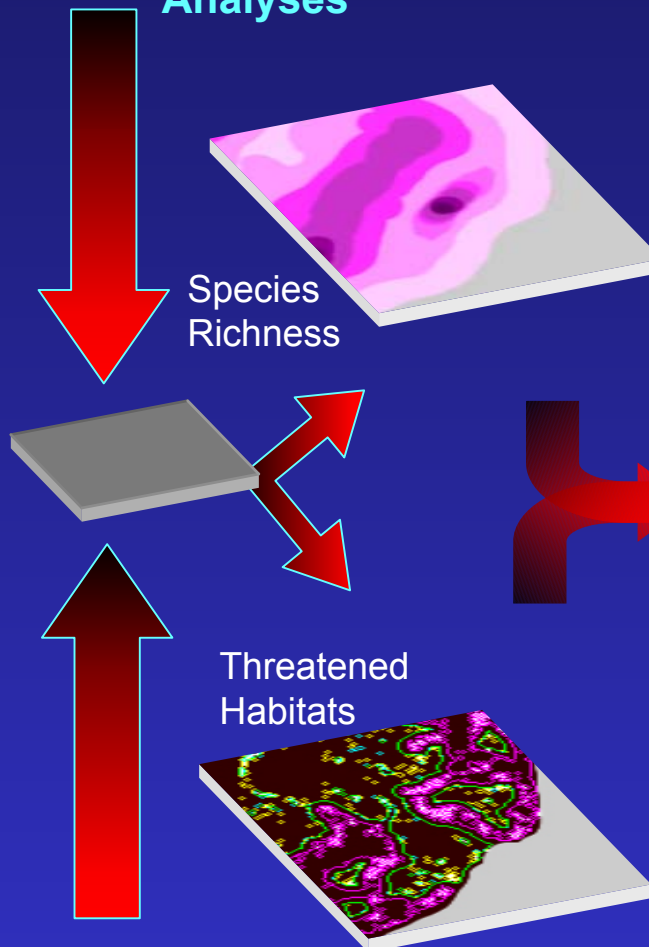
The Biogeographic Assessment Process

Individual Biogeographic Data Layers



Combine Biogeographic Layers for Analysis

Example Integrated Biogeographic Analyses*



Products to Aid Natural Resource Management

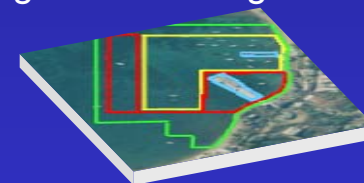
Evaluate current management boundaries relative to biological resources



Explore options for protecting additional management areas



Evaluate Alternative Management Strategies



Analytical Products to meet Management Objectives

<http://biogeo.nos.noaa.gov/>